Obesity Facts
The European Journal of Obesity

Obes Facts 2019;12:14–24

DOI: 10.1159/000496118
Received: January 19, 2018
Accepted: December 9, 2018
Published online: January 23, 2019

Research Article

The Moderating Role of Social Neighbourhood Factors in the Association between Features of the Physical Neighbourhood Environment and Weight Status

Jody C. Hoenink[a] Jeroen Lakerveld[a] Harry Rutter[b] Sofie Compernolle[c] Ilse De Bourdeaudhuij[c] Helga Bárdos[d] Helene Charreire[e, f] Jean Michel Oppert[f, g] Joreintje D. Mackenbach[a]

[a]Department of Epidemiology and Biostatistics, Amsterdam Public Health Research Institute, VU Medical Centre Amsterdam, Amsterdam, The Netherlands; [b]Department of Social & Policy Sciences, University of Bath, Bath, UK; [c]Department of Movement and Sport Sciences, Ghent University, Ghent, Belgium; [d]Department of Preventive Medicine, Faculty of Public Health, University of Debrecen, Debrecen, Hungary; [e]Université Paris Est, LabUrba, UPEC, Créteil, France; [f]Equipe de Recherche en Epidémiologie Nutritionnelle (EREN), Centre de Recherche en Epidémiologie et Statistiques, Inserm (U1153), Inra (U1125), Cnam, COMUE Sorbonne Paris Cité, Université Paris 13, Bobigny, France; [g]Sorbonne Université Institute of Cardiometabolism and Nutrition, Department of Nutrition, Pitié-Salpêtrière Hospital, Assistance Publique-Hôpitaux de Paris, Paris, France

Keywords

Socio-ecological model · Weight status · Physical environment · Social factors · Adults

Abstract

Background: This paper investigated the independent and joint associations between aspects of the physical neighbourhood environment and social neighbourhood factors with BMI and overweight status in European adults. ***Methods:*** Data from 5,199 participants in the SPOTLIGHT survey were analysed. Participants reported on their height, weight and perceptions of the neighbourhood. Objectively measured aspects of the physical neighbourhood environment included: presence of recreational facilities, features of the active transportation environment, neighbourhood aesthetics and presence of different types of food outlets. Social factors included the self-reported variables social network, social cohesion, social trust and perceived crime and the census variable neighbourhood socioeconomic status. Outcome measures were BMI and overweight status. Main associations between physical and social factors and BMI/overweight status were analysed using multilevel regression analyses adjusted for confounders. Moderation analysis was conducted by adding the interaction terms between physical and social neighbourhood factors one by one to the multivariable models.

Joreintje D. Mackenbach
Department of Epidemiology and Biostatistics, Amsterdam Public Health Research Institute, VU Medical Centre Amsterdam
De Boelelaan 1089a
NL–1081 HV Amsterdam (The Netherlands)
E-Mail j.mackenbach@vumc.nl

Obes Facts 2019;12:14–24
DOI: 10.1159/000496118

Significant interaction terms were then stratified. ***Results:*** Significant associations with BMI/overweight status were found for features of the active transportation environment and all social factors, except perceived crime. Several significant interaction terms were detected, but no significant associations between the physical neighbourhood environment and BMI/overweight status were found after stratification. ***Conclusion:*** We did not find consistent interactions between physical and social neighbourhood factors to explain BMI and overweight status.

Introduction

Increasing obesity rates in Europe and elsewhere are the result of a complex web of interacting individual and environmental level factors influencing energy balance [1]. Preventing and/or combating obesity has become a global public health issue [2], and there is increasing interest in better understanding the influence of upstream determinants of obesity such as the physical and social environments within which people live [3]. Increasing our understanding of the mechanisms through which the physical and social neighbourhood environment may influence body weight and obesity is crucial to effectively combat the current obesity epidemic [4]. There is some evidence that physical neighbourhood environmental characteristics such as limited access to sidewalks [5, 6], low aesthetics [5], low walkability areas [7, 8], larger distance to recreational facilities [6, 9] and higher fast food density [10, 11] are linked to higher body weights and obesity [12, 13]. Conversely, one longitudinal study conducted in Canada found that higher neighbourhood walkability was associated with lower prevalence of overweight and obesity [14]. Also, some evidence suggests that positive perceptions of the social neighbourhood environment (i.e. psychosocial variables such as social support, social cohesion and trust, and other social neighbourhood factors such as crime, traffic safety and socioeconomic status) are associated with higher levels of physical activity [15, 16] and/or lower levels of obesity [16–18].

Socio-ecological models of health behaviour highlight the importance of investigating interactions between multiple levels of health behaviour influences. While an expanding literature base investigates the independent effects of physical and social environmental factors, few studies have actually investigated the interplay between different physical and social neighbourhood characteristics [19–22]. Research into such moderating effects is recommended to gain insight into the complex relationships between neighbourhood physical and social environments and weight status. It is important to investigate this interplay because it may be that positive social factors help overcome the negative influences of less favourable physical environments, that both a positive physical and social environment are required for maintaining a healthy weight status, or that certain physical environmental aspects are especially important for some social groups. For example, one study found that residents with access to parks and who lived in moderately or highly deprived areas were more likely to be obese compared to residents living in less deprived areas with park access [23].

Several studies have investigated the independent influences of the physical and social neighbourhood environment on obesity. However, to our knowledge, only one study to date has investigated the interactions between the physical and social neighbourhood factors in relation to body weight in adults [23]. The scientific value of investigating both physical and social factors together is to unfold the interacting effects through which the environment influences health behaviours as hypothesised by socio-ecological models [22]. Therefore, the main purpose of this exploratory study was to investigate the moderating role of social neigh-

Obes Facts 2019;12:14–24
DOI: 10.1159/000496118

bourhood factors in the relation between aspects of the physical neighbourhood environment and weight status in a large sample of European adults. Additionally, main associations of physical and social neighbourhood factors with weight status were investigated.

Material and Methods

Study Design and Sampling

This cross-sectional study was part of the SPOTLIGHT ("Sustainable Prevention of Obesity through Integrated Strategies") project [24]. The SPOTLIGHT project gathered data from five urban areas across Europe: Ghent and suburbs in Belgium, Paris and suburbs in France, Budapest and suburbs in Hungary, the Randstad in the Netherlands and Greater London in the UK [24]. Details regarding the sampling of residential neighbourhoods and the recruitment of participants have been described elsewhere [24]. Briefly, neighbourhoods were defined using small-scale local administrative boundaries as used in each country, except for Hungary where 1 km^2 areas were used to represent neighbourhoods in Budapest and suburbs. Sampling of neighbourhoods was based on a combination of socio-economic levels (SES) and residential area density levels (RAD) at neighbourhood scale. Four types of pre-specified neighbourhoods were selected: low SES/low RAD, low SES/high RAD, high SES/low RAD and high SES/high RAD. In each country, three neighbourhoods of each neighbourhood type were randomly sampled, resulting in twelve neighbourhoods in each country, and 60 in total [24]. Subsequently, a random selection of 55,893 adults living in the selected neighbourhoods were invited by regular mail to participate in an online survey. Data were collected between February and September 2014 among 6,037 participants, and the response rate was 10.8% [24]. The SPOTLIGHT study was approved by the corresponding local ethics committees of participating countries, and all participants in the survey provided informed consent.

Measures

Outcome Variables: BMI and Overweight

Self-reported height and weight were used to calculate BMI (kg/m^2). BMI was dichotomised according to the WHO cut-off defining overweight (BMI $\geq$ 25 kg/m^2) [25]. Both BMI (continuous variable) and overweight status (categorical variable) were used as outcome measures.

Neighbourhood Physical Environment

Neighbourhood physical environmental factors were objectively measured using the validated SPOTLIGHT-Virtual Audit Tool (S-VAT). The S-VAT was developed to objectively assess obesogenic neighbourhood characteristics of environments, as previously described [26]. Street segments within neighbourhoods were assessed for the availability of obesity-related physical environmental factors through the Google Street View function within Google Earth. Street segment level data were aggregated to the neighbourhood level by taking the percentage of street segments with each feature in the neighbourhood. In addition, the S-VAT enabled the collection of geographic locations of food retailers in the neighbourhood. A validation study concluded that the virtual audit based on the S-VAT is a valid and reliable way to assess neighbourhood characteristics that may be associated with physical activity and dietary behaviours [26].

We constructed three variables reflecting the activity-friendliness of neighbourhoods according to a previous study identifying ten indicators of activity-friendly neighbourhoods through a comprehensive literature review and a three-tiered modified Delphi consensus-development process [27]. The operationalisation and scoring of the constructs in this study is described in supplementary Table 1 (available at *http://content.karger.com/ProdukteDB/produkte.asp?doi=499118*)). First, based on their distribution, the percentage of street segments with indoor recreational facilities, outdoor recreational facilities and public parks were divided into two or three categories. By summing these scores, the variable *presence of recreational facilities* was then constructed, which ranged from 3 to 7. Indoor recreational facilities included facilities such as gyms, swimming pools and sports clubs, and outdoor recreational facilities included facilities such as outdoor fitness areas, skate parks and soccer courts. Public parks were defined as natural recreation areas that are maintained and publicly accessible. Second, the percentage of street segments with sidewalks, crossings, well maintained sidewalks, street lights, bicycle lanes, obstacles and public bicycle facilities were divided into two or three categories. By summing these scores, the variable *features of the active transportation environment* was then constructed, which ranged from 7 to 19. Third, the percentage of street segments with graffiti, litter, trees, residential gardens, green/water area visible and public parks were divided into two or three categories. By summing these scores, the variable *neighbourhood aesthetics* was then constructed, which ranged from 6 to 17. *Neighbourhood aesthetics* reflects the presence of natural attractions (i.e. residential gardens and water areas) and the absence of physical disorder.

Using the geographic location of supermarkets, local food shops, restaurants, fast food and takeaway restaurants, and café/bars present in a neighbourhood, we calculated the number of each of these outlets present in a neighbourhood. With these data, we constructed a modified retail food environment index (mRFEI), which represents the percentage of healthy stores within a neighbourhood (calculated by dividing the number of healthy food outlets by the total number of healthy and unhealthy food outlets and multiplying this by 100) [28]. This study regarded supermarkets and local food shops (e.g. butchers, greengrocers) as healthy food outlets, and fast food and takeaway places, restaurants and café/bars as unhealthy food outlets.

Social Neighbourhood Factors

Individual participants reported on a number of social environmental characteristics. At the basis of a 13-item 5-point Likert scale questionnaire on social capital, we constructed a reliable social network (α = 0.83) and social cohesion score (α = 0.79), as previously reported [29]. Social network was assessed using questions such as “I often visit my neighbours in their homes” and “I can always ask my neighbours if I need advice”. Social cohesion was assessed using questions such as “Most people in this neighbourhood get on with one another” and “Most people in this neighbourhood can be trusted”. A summary score was calculated for the two constructs, ranging from 4 to 20 for social network and 5 to 25 for social cohesion. We also separately analysed the single item regarding social trust. Neighbourhood SES was estimated using neighbourhood level income data [24] and dichotomised into low and high SES, as used for the neighbourhood sampling approach [24]. Perceived crime was assessed using the single question “There is a high level of crime in my neighbourhood”, rated on a 5-point Likert scale.

Covariates

The individual-level measures of age, sex, educational level and length of residency in the neighbourhood were gathered through the SPOTLIGHT survey questionnaire. Given the large differences between the education systems across the five European countries, educational level was operationalised as “higher education” (college or university level) or “lower education” (higher secondary education or less) [30]. The neighbourhood-level measure RAD was obtained from the Urban Atlas database [24]. Also, the neighbourhood-level measure SES was included as a covariate except for the analyses in which SES was the determinant.

Statistical Analyses

Data from 59 out of 60 neighbourhoods were used (Google Street View did not cover one Hungarian neighbourhood at the time of the virtual audit). Individuals were excluded from the analyses if they lived in that Hungarian neighbourhood (n = 88), if they had missing data regarding the neighbourhood they lived in (n = 137) or if their residential addresses were located outside the selected neighbourhoods (n = 613). Consequently, a sample of 5,199 participants was available for analyses regarding the variables reflecting the activity friendliness of neighbourhoods. A sample of n = 4,942 participants was available for the analyses with the food environment variable. Two Hungarian participants were excluded from the analyses because the exact location of food outlets in the neighbourhood for these two participants was unknown. Additionally, for 255 participants, the mRFEI could not be calculated because they lived in a Dutch neighbourhood in which information was not collected on the exact location of food outlets or they lived in a neighbourhood in which no food outlets were present. Thus, analyses with the mRFEI was restricted to participants with known food outlets present in the neighbourhood (n = 4,942).

Descriptive statistics were computed for all variables, using percentages and mean with standard deviation. Item non-response ranged from 1% (age) to 11.3% (BMI) (Table 1). Missing values for all variables were imputed using predictive mean matching based on the assumption that data were missing at random. All variables described in the “Methods” section were used as predictors in the imputation model to create 30 imputed datasets. The intra-class correlation coefficient determined that there was clustering of individuals within neighbourhoods. Therefore, multilevel analyses were conducted using a two-level generalised estimating equation (GEE) with an exchangeable structure. GEE was used to examine associations between physical and social neighbourhood factors and the outcome variables BMI and overweight status as well as moderating effects of social neighbourhood factors in the association between the physical neighbourhood environment and BMI/overweight status. Separate multivariable models for each physical neighbourhood

Obes Facts 2019;12:14–24
DOI: 10.1159/000496118

Table 1. Characteristics of the study population (n = 5,199) and descriptive information regarding the physical and social environment in neighbourhoods

Sociodemographic characteristics	*n*	Mean (SD) or percentages
Age in years	5,149	52.2 (16.3)
Sex (% female)	5,148	55.3
Educational level (% higher)	4,703	54.1
Length of residency (10 years or more)	4,994	65.0
BMI (kg/m^2)	4,614	25.2 (4.5)
Overweight status (% BMI ≥25.0)	4,614	45.3
Physical neighbourhood factors (range)		
Neighbourhood-level RAD (% high)	5,199	49.6
Presence of recreational facilities*, [1] (3–7)	5,199	4.8 (1.1)
Features of the active transportation environment*, [1] (7–19)	5,199	12.6 (2.8)
Neighbourhood aesthetics*, [1] (6–17)	5,199	11.5 (2.4)
mRFEI (0–100)	4,942	43.2 (24.4)
Social neighbourhood factors		
Social network construct*, [2]	4,790	10.4 (3.7)
First tertile (social network score <9)	1,545	32.3
Second tertile (social network score ≥9 and ≤12)	1,837	38.4
Third tertile (social network score >12)	1,408	29.4
Social cohesion construct*, [2]	4,758	17.4 (3.6)
First tertile (social cohesion score <16)	1,284	27.0
Second tertile (social cohesion score ≥16 and ≤19)	2,067	43.4
Third tertile (social cohesion score >19)	1,407	29.6
Social trust*, [2]	4,891	3.5 (0.9)
Strongly disagree	204	4.2
Disagree	342	7.0
Neither agree or disagree	1,591	32.5
Agree	2,299	47.0
Strongly agree	455	9.3
Neighbourhood SES (% high)	5,199	50.4
Perceived crime*, [2]	4,819	3.4 (1.1)
Strongly disagree	664	13.8
Disagree	1,712	35.5
Neither agree or disagree	1,544	32.0
Agree	581	12.1
Strongly agree	318	6.6

* Individual sum scores. [1] Higher scores indicate a more activity-friendly neighbourhood. [2] Higher scores indicate more social networks, or higher social trust, or social cohesion, or perceived crime. BMI, body mass index measured in kg/m^2; RAD, residential area density; mRFEI, modified retail food environment index calculated by dividing the number of healthy food outlets by the total number of healthy and unhealthy food outlets and multiplying this by 100; SES, socio-economic status.

factor and outcome were ran adjusting for age, sex, educational level, length of residency, neighbourhood RAD and neighbourhood SES (if it was no moderating factor). Then, interaction terms between the physical and social neighbourhood factors were added one by one to each multivariable model. Statistically significant moderating roles of social factors in the association between physical factors and BMI/overweight status were stratified. All analyses were conducted using SPSS version 22.0, and statistical significance was set at a two-sided p value of <0.05 for interpreting main and moderating effects. Sensitivity analysis was conducted using the non-imputed dataset (i.e. complete cases).

Obes Facts 2019;12:14–24
DOI: 10.1159/000496118

Table 2. Results indicating the number of participants, coefficients, odds ratios and 95% confidence intervals regarding the direct association between physical neighbourhood factors and BMI/overweight status and the direct association between social neighbourhood factors and BMI/overweight status as derived from multilevel linear (BMI) and logistic (overweight) regression analysis in multiple imputed data

	n	BMI		Overweight	
		B	95%CI	OR	95% CI
Physical neighbourhood factors					
Presence of recreational facilities	5,199	–0.10	–0.31; 0.11	0.96	0.87; 1.06
Features of the active transportation environment	5,199	**–0.21**	**–0.40; –0.02**	**0.91**	**0.83; 0.99**
Neighbourhood aesthetics	5,199	–0.02	–0.20; 0.16	1.00	0.92; 1.08
mRFEI	4,942	–0.00	–0.01; 0.01	1.00	0.99; 1.00
Social neighbourhood factors					
Low social network	1,682	ref		ref	
Moderate social network	1,989	**–0.43**	**–0.75; –0.10**	0.89	0.76; 1.06
High social network	1,528	**–0.42**	**–0.77; –0.06**	0.94	0.78; 1.13
Low social cohesion	1,420	ref		ref	
Moderate social cohesion	2,258	**–0.56**	**–0.84; –0.28**	**0.85**	**0.75; 0.98**
High social cohesion	1,520	**–0.48**	**–0.85; –0.11**	0.95	0.89; 1.25
Lowest social trust	220	ref		ref	
Low social trust	368	–0.87	–1.83; 0.09	0.94	0.65; 1.36
Neutral social trust	1,696	–0.92	–1.86; 0.02	0.97	0.70; 1.35
High social trust	2,436	**–1.28**	**–2.12; –0.44**	0.85	0.64; 1.14
Highest social trust	479	**–1.31**	**–2.19; –0.43**	0.88	0.62; 1.25
Low SES	2,578	ref		ref	
High SES	2,621	**–0.75**	**–1.15; –0.35**	**0.73**	**0.61; 0.89**
Lowest perceived crime	715	ref		ref	
Low perceived crime	1,845	–0.15	–0.52; 0.22	1.02	0.86; 1.21
Neutral perceived crime	1,667	–0.14	–0.53; 0.25	1.01	0.83; 1.23
High perceived crime	628	0.13	–0.38; 0.64	1.05	0.83; 1.34
Highest perceived crime	344	–0.27	–0.82; 0.28	0.97	0.74; 1.27

Physical neighbourhood factors are operationalised as z-scores, except for mRFEI. All analyses, except for SES, were adjusted for age, sex, educational level, length of residency, RAD and SES. Analyses with SES were adjusted for age, sex, educational level, length of residency and RAD. *n*, number of participants; B, unstandardized coefficients; 95% CI, 95% confidence interval; BMI, body mass index measured in kg/m^2; OR, odds ratio; mRFEI, modified retail food environment index calculated by dividing the number of healthy food outlets by the total number of healthy and unhealthy food outlets and multiplying this by 100; SES, socio-economic status; ref, reference; RAD, residential area density. Bold numbers represent significant associations (two-sided *p* value <0.05).

Results

Participant characteristics and descriptive statistics of independent variables are presented in Table 1. Mean age of the participants was 52 years, and mean BMI was 25.2 kg/m^2, with approximately 45% classified as being overweight or obese.

Physical Neighbourhood Factors and BMI/Overweight Status

The results regarding the independent associations between several physical neighbourhood factors and BMI/overweight status can be seen in Table 2. Only the construct “features of the active transportation environment” was negatively associated with BMI (B = –0.21, 95% CI = –0.40; –0.02) and overweight status (OR = 0.91, 95% CI = 0.83; 0.99). A one standard deviation increase in the "features of the active transportation environment" score was associated with a 0.21 kg/m^2 decrease in BMI and a 9% decreased odds of being overweight. No significant associations were found between the physical factors presence of recreational facilities, neighbourhood aesthetics or the mRFEI and the outcome measures BMI and overweight status.

Social Neighbourhood Factors and BMI/Overweight Status

The results regarding the independent associations between several social neighbourhood factors and BMI/overweight status are shown in Table 2. Social network was significantly associated with BMI, but not with overweight status. Both moderate and high social network levels within neighbourhoods were associated with a more than 0.40 kg/m^2 decrease in BMI compared to low social network levels within neighbourhoods (Table 2). Social cohesion was significantly associated with BMI and overweight status. Moderate social cohesion levels within neighbourhoods was associated with a 0.56 kg/m^2 (95% CI = –0.84; –0.28) decrease in BMI compared to low social network levels within neighbourhoods, which is a higher decrease in BMI than in neighbourhoods with high social cohesion levels (B = –0.48, 95% CI = –0.85; –0.11). Participants living in neighbourhoods with moderate social cohesion levels had a 15% lower odds of overweight than participants living in neighbourhoods with low social cohesion levels. Furthermore, only high social trust levels within neighbourhoods was significantly associated to BMI (high social trust: B = –1.28, 95%CI = –2.12; –0.44, highest social trust: B = –1.31, 95% CI = –2.19; –0.43). Social trust was not significantly associated to overweight status. Additionally, neighbourhood SES was associated with both BMI and overweight status, indicating that high neighbourhood SES was associated with a 0.75 kg/m^2 decrease in BMI and a 27% decreased odds of overweight compared to low neighbourhood SES. Lastly, perceived crime was not associated with either BMI or overweight status.

Moderation Effects by Social Neighbourhood Factors

Several significant interactions between physical and social neighbourhood factors in either the main analyses or the sensitivity analysis (complete case analysis) were found (supplementary Table 2, available at *http://content.karger.com/ProdukteDB/produkte.asp?doi=499118*). Firstly, presence of recreational facilities interacted with social cohesion levels for BMI with non-imputed data. Secondly, neighbourhood aesthetics interacted with social network levels for BMI and overweight status. Social cohesion and social networks did not interact with any other physical neighbourhood factors for BMI, overweight status or the sensitivity analysis. The social factors social trust, neighbourhood SES and perceived crime did not interact with any of the physical neighbourhood factors for BMI, overweight status or the sensitivity analysis.

Following significant interactions between physical and social neighbourhood factors for overweight status and the sensitivity analysis, associations were stratified by social neighbourhood factors. After stratification, no significant associations between physical neighbourhood factors and BMI or overweight status were detected (supplementary Table 3, available at *http://content.karger.com/ProdukteDB/produkte.asp?doi=499118*).

Discussion

This study examined the independent and joint associations of physical and social environmental neighbourhood factors with BMI and overweight status. Associations between features of the active transportation environment and BMI/overweight status were observed,

Obes Facts 2019;12:14–24
DOI: 10.1159/000496118

but not with the other three physical neighbourhood factors: presence of recreational facilities, neighbourhood aesthetics and the mRFEI. Additionally, associations between all favourable social neighbourhood factors and BMI, and associations between moderate social cohesion and neighbourhood SES and overweight status were found. Several significant interaction terms were detected; presence of recreational facilities interacted with social cohesion, and neighbourhood aesthetics interacted with social networks. However, no significant associations between physical neighbourhood factors and BMI/overweight status were found after stratification for the social neighbourhood factors social networks and social cohesion.

Our results are partly in line with other studies showing that features of the active transportation environment such as poor access to sidewalks [5, 6, 9] are associated with walking and/or cycling behaviours built into the daily routine (e.g., active commuting) which may influence BMI levels and overweight status. Our finding, also shown previously [10, 23, 31], that the presence of recreational facilities was not associated with body weight can be due to the fact that recreational leisure time only constitutes a small part of total physical activity, thereby having limited effects on body weight. In contrast to our findings, previous studies have shown that poor neighbourhood aesthetics and aspects of the food environment were associated with increased obesity risk [5, 9, 32, 33]. However, previous studies linking the retail food environment index and BMI [32] or obesity [33] were conducted in the US, where food environments differ from those in Europe. Also, previous studies mostly used single neighbourhood aesthetic items [5, 9]. Indeed, another study using an indexed neighbourhood aesthetics measure, as was done in the present study, found that neighbourhood aesthetics was not associated with walking for exercise, dog walking or walking for transportation in women [34].

In line with previous studies [4, 16, 35–37], our study showed that urban residential neighbourhoods characterized by a more favourable social environment (e.g. having high social trust or social cohesion) are linked to lower BMI levels and odds of overweight. Social networks may influence health behaviours such as smoking and exercise by providing social support, applying social influence and encouraging social engagement [37]. Similarly, social cohesion may reflect the willingness to express (dis)approval about these health behaviours [4], in turn influencing body weight. Also, SES seems to influence physical activity levels and dietary behaviours; research has shown that individuals in deprived areas are less physically active and consume more energy-dense foods compared to individuals in wealthier areas [38, 39]. Similar to other studies, this study found no significant association between crime and BMI or overweight status [15, 31], indicating that perceived crime safety may be less important than perceived social safety (i.e. social trust) for body weight [19].

The present study showed that some physical as well as social environmental factors were significantly associated with body weight, supporting socio-ecological models positing that health behaviours are caused by multiple levels of environmental influences. However, the notion that there are interactions between influences at different levels of the model was not completely supported by the current study findings. Results from the moderation analysis indicated only a few significant interactions (i.e. between presence of recreational facilities with social cohesion and neighbourhood aesthetics with social networks). These findings highlight the intricate relationship between the residential environment and behaviour, since both presence of recreational facilities and neighbourhood aesthetics were not independently associated with BMI or overweight status. The lack of significant associations after stratification, and the small effect sizes throughout, may be explained by the long path through which the physical environment is associated with BMI/overweight status. For example, we hypothesized that availability of opportunities for active transportation (i.e. objective measures of the environment) may lead to increased awareness of these opportunities (i.e.

Obes Facts 2019;12:14–24
DOI: 10.1159/000496118

subjective measures of the environment), leading to increased use of these opportunities, which in turn leads to increased physical activity, and then leads to decreased weight. Since previous studies have provided evidence for a mismatch between objective environmental measures and inhabitants perceptions of the environment (i.e. subjective measures of the environment) [40], more research is needed into whether the perceptions of the environment are in fact a mediating factor or a moderating factor in the association between objective environmental factors and body weight. For example, a study indicated that approximately 32% of participants living in highly walkable neighbourhoods misperceived their neighbourhoods to be lowly walkable [41].

To our knowledge, this is one of the first studies to investigate the moderating role of social neighbourhood factors in the association between the physical environment and body weight. Replication studies in similar and different populations and settings are needed to explore these relations further. Future studies could focus on whether and how social factors moderate the relation of subjectively measured physical factors and other physical factors such as residential density level, urban sprawl, walkability level and land-use mix with body weight. Also, more extensive measures of the social environment could be used in future studies.

The results indicated that social neighbourhood factors were more strongly correlated with BMI and overweight status compared to physical neighbourhood factors. Therefore, interventions aimed at improving social networks, social cohesion, social trust and socioeconomic position in neighbourhoods may be more effective in combating the current obesity epidemic than changing the physical environment. However, it is unclear how social factors such as social cohesion are formed [4]. On the other hand, addressing the physical neighbourhood environment may be more straightforward. Interventions aimed at reducing obesity levels by increasing the activity friendliness of neighbourhoods can increase features of the active transportation environment by adding crossings, street lights etc. A combination of disciplines should ideally be involved in such research and intervention efforts, including economists, sociologists, anthropologists, education specialists, public health and urban planners, to fully integrate the physical and social environment in designing policies and measures for combating the current obesity epidemic [3, 42].

This study has several strengths, of which the first is the large sample size recruited from five European countries, increasing the generalisability of the results within the European region. Furthermore, most previous studies investigating the physical environment in relation to weight status were conducted in the US, whereas this study used data from European countries. Additionally, validated tools were used to assess aspects of the physical and social neighbourhood environment. Another strength includes the use of indexed measures as physical neighbourhood factors. However, the indexed physical measures also lead to more heterogeneity. A first limitation was that this study relied on cross-sectional data, and thus causal relationships could not be identified. Furthermore, the study may also have been underpowered to detect rather small main and interaction effects. Also, due to the low response rate, generalisation of outcomes should be done with caution as selection bias may have taken place [24]: high BMI or low educational level may predict non-response, and country-specific 'survey fatigue' may also have played a role. Lastly, BMI was not objectively measured but self-reported. Research has indicated that people tend to underestimate their weight status, especially in groups with lower SES [43].

In conclusion, we found evidence that the active transportation environment, social networks, social cohesion, social trust and neighbourhood SES were independently associated with BMI and overweight. In addition, we found some evidence for interaction effects between the physical and social neighbourhood environment, but stratified analyses did not reveal meaningful associations. The evidence from this study, complemented by findings from future studies that take into account complementary aspects of the physical and social environment, may provide entry points for community-based interventions aimed at altering the physical and/or social environment with the aim of reducing the prevalence of overweight and obesity [44].

Declaration of Interest

The authors have no conflicts of interest to declare.

Acknowledgements

The SPOTLIGHT project was funded by the Seventh Framework Programme (CORDIS FP7) of the European Commission, HEALTH (FP7-HEALTH-2011-two-stage), grant agreement no. 278186. The content of this article reflects only author's views, and the European Commission is not liable for any use that may be made of the information contained therein. HR was supported by the UK National Institute for Health Research (NIHR) Collaboration for Leadership in Applied Health Research and Care (CLAHRC) North Thames at Bart's Health NHS Trust.

References

1 Rutter H, Bes-Rastrollo M, de Henauw S, Lahti-Koski M, Lehtinen-Jacks S, Mullerova D, et al. Balancing Upstream and Downstream Measures to Tackle the Obesity Epidemic: A Position Statement from the European Association for the Study of Obesity. Obes Facts. 2017;10(1):61–3.
2 Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet. 2014 Aug;384(9945):766–81.
3 Lakerveld J, Mackenbach J. The Upstream Determinants of Adult Obesity. Obes Facts. 2017;10(3):216–22.
4 Cohen DA, Finch BK, Bower A, Sastry N. Collective efficacy and obesity: the potential influence of social factors on health. Soc Sci Med. 2006 Feb;62(3):769–78.
5 Boehmer TK, Hoehner CM, Deshpande AD, Brennan Ramirez LK, Brownson RC. Perceived and observed neighborhood indicators of obesity among urban adults. Int J Obes. 2007 Jun;31(6):968–77.
6 Giles-Corti B, Macintyre S, Clarkson JP, Pikora T, Donovan RJ. Environmental and lifestyle factors associated with overweight and obesity in Perth, Australia. Am J Health Promot. 2003 Sep-Oct;18(1):93–102.
7 Saelens BE, Sallis JF, Black JB, Chen D. Neighborhood-based differences in physical activity: an environment scale evaluation. Am J Public Health. 2003 Sep;93(9):1552–8.
8 Creatore MI, Glazier RH, Moineddin R, Fazli GS, Johns A, Gozdyra P, et al. Association of Neighborhood Walkability with Change in Overweight, Obesity, and Diabetes. JAMA. 2016 May;315(20):2211–20.
9 Boehmer TK, Lovegreen SL, Haire-Joshu D, Brownson RC. What constitutes an obesogenic environment in rural communities? Am J Health Promot. 2006 Jul-Aug;20(6):411–21.
10 Prince SA, Kristjansson EA, Russell K, Billette JM, Sawada MC, Ali A, et al. Relationships between neighborhoods, physical activity, and obesity: a multilevel analysis of a large Canadian city. Obesity (Silver Spring). 2012 Oct;20(10):2093–100.
11 Mackenbach JD, Charreire H, Glonti K, Bárdos H, Rutter H, Compernolle S, et al. Exploring the Relation of Spatial Access to Fast Food Outlets With Body Weight: A Mediation Analysis. Environ Behav. 2018;doi: 10.1177/00391651774987.
12 Mackenbach JD, Rutter H, Compernolle S, Glonti K, Oppert JM, Charreire H, et al. Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. BMC Public Health. 2014 Mar;14(1):233.
13 Black JL, Macinko J. Neighborhoods and obesity. Nutr Rev. 2008 Jan;66(1):2–20.
14 Creatore MI, Glazier RH, Moineddin R, Fazli GS, Johns A, Gozdyra P, et al. Association of neighborhood walkability with change in overweight, obesity, and diabetes. JAMA -. JAMA. 2016 May;315(20):2211–20.
15 Ball K, Cleland VJ, Timperio AF, Salmon J, Giles-Corti B, Crawford DA. Love thy neighbour? Associations of social capital and crime with physical activity amongst women. Soc Sci Med. 2010 Aug;71(4):807–14.
16 Poortinga W. Perceptions of the environment, physical activity, and obesity. Soc Sci Med. 2006 Dec;63(11):2835–46.
17 Glonti K, Mackenbach JD, Ng J, Lakerveld J, Oppert JM, Bárdos H, et al. Psychosocial environment: definitions, measures and associations with weight status – a systematic review. Obes Rev. 2016 Jan;17 Suppl 1:81–95.
18 Leal C, Chaix B. The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. Obes Rev. 2011 Mar;12(3):217–30.

19 Bracy NL, Millstein RA, Carlson JA, Conway TL, Sallis JF, Saelens BE, et al. Is the relationship between the built environment and physical activity moderated by perceptions of crime and safety? Int J Behav Nutr Phys Act. 2014 Feb;11(1):24.
20 Van Holle V, Van Cauwenberg J, De Bourdeaudhuij I, Deforche B, Van de Weghe N, Van Dyck D. Interactions between neighborhood social environment and walkability to explain belgian older adults physical activity and sedentary time. Int J Environ Res Public Health. 2016 Jun;13(6):110.
21 Carlson JA, Sallis JF, Conway TL, Saelens BE, Frank LD, Kerr J, et al. Interactions between psychosocial and built environment factors in explaining older adults' physical activity. Prev Med. 2012 Jan;54(1):68–73.
22 Sawyer A, Ucci M, Jones R, Smith L, Fisher A. Simultaneous evaluation of physical and social environmental correlates of physical activity in adults: A systematic review. SSM-Population Heal; 2017. https://doi.org/10.1016/j.ssmph.2017.05.008.
23 Hobbs M, Green M, Griffiths C, Jordan H, Saunders J, Grimmer H, et al. Access and quality of parks and associations with obesity: A cross-sectional study. SSM-Population Heal; 2017 Dec ;3:722–9.
24 Lakerveld J, Ben Rebah M, Mackenbach JD, Charreire H, Compernolle S, Glonti K, et al. Obesity-related behaviours and BMI in five urban regions across Europe: sampling design and results from the SPOTLIGHT cross-sectional survey. BMJ Open. 2015 Oct;5(10):e008505.
25 World Health Organization. Obesity and overweight 2016;Available from: http://www.who.int/mediacentre/factsheets/fs311/en/
26 Bethlehem JR, Mackenbach JD, Ben-Rebah M, Compernolle S, Glonti K, Bárdos H, et al. The SPOTLIGHT virtual audit tool: a valid and reliable tool to assess obesogenic characteristics of the built environment. Int J Health Geogr. 2014 Dec;13(1):52.
27 Brennan Ramirez LK, Hoehner CM, Brownson RC, Cook R, Orleans CT, Hollander M, et al. Indicators of activity-friendly communities: an evidence-based consensus process. Am J Prev Med. 2006 Dec;31(6):515–24.
28 Center for Disease Control and Prevention (CDC). Healthier food retail: Beginning the assessment process in your state or community. Atlanta US Dep Heal Hum Serv; 2014. Available from: https://www.cdc.gov/obesity/downloads/hfrassessment.pdf
29 Mackenbach JD, Lakerveld J, van Lenthe FJ, Kawachi I, McKee M, Rutter H, et al. Neighbourhood social capital: measurement issues and associations with health outcomes. Obes Rev. 2016 Jan;17 Suppl 1:96–107.
30 Mackenbach JD, Lakerveld J, Van Lenthe FJ, Teixeira PJ, Compernolle S, De Bourdeaudhuij I, et al. Interactions of individual perceived barriers and neighbourhood destinations with obesity-related behaviours in Europe. Obes Rev. 2016 Jan;17 Suppl 1:68–80.
31 Prince SA, Kristjansson EA, Russell K, Billette JM, Sawada M, Ali A, et al. A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada. Int J Environ Res Public Health. 2011 Oct;8(10):3953–78.
32 Jilcott SB, McGuirt JT, Imai S, Evenson KR: Measuring the retail food environment in rural and urban North Carolina counties. J Public Heal Manag Pract 2010;16:432–40.
33 Spence JC, Cutumisu N, Edwards J, Raine KD, Smoyer-Tomic K. Relation between local food environments and obesity among adults. BMC Public Health. 2009 Jun;9(1):192.
34 Suminski RR, Poston WS, Petosa RL, Stevens E, Katzenmoyer LM. Features of the neighborhood environment and walking by U.S. adults. Am J Prev Med. 2005 Feb;28(2):149–55.
35 Regidor E, Gutiérrez-Fisac JL, Ronda E, Calle ME, Martínez D, Domínguez V. Impact of cumulative area-based adverse socioeconomic environment on body mass index and overweight. J Epidemiol Community Health. 2008 Mar;62(3):231–8.
36 McCormack GR, Friedenreich C, McLaren L, Potestio M, Sandalack B, Csizmadi I. Interactions between Neighbourhood Urban Form and Socioeconomic Status and Their Associations with Anthropometric Measurements in Canadian Adults. J Environ Public Health. 2017;2017:5042614.
37 Veenstra G, Luginaah I, Wakefield S, Birch S, Eyles J, Elliott S. Who you know, where you live: social capital, neighbourhood and health. Soc Sci Med. 2005 Jun;60(12):2799–818.
38 Beenackers MA, Kamphuis CB, Giskes K, Brug J, Kunst AE, Burdorf A, et al. Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. Int J Behav Nutr Phys Act. 2012 Sep;9(1):116.
39 Giskes K, Avendaňo M, Brug J, Kunst AE. A systematic review of studies on socioeconomic inequalities in dietary intakes associated with weight gain and overweight/obesity conducted among European adults. Obes Rev. 2010 Jun;11(6):413–29.
40 Roda C, Charreire H, Feuillet T, Mackenbach JD, Compernolle S, Glonti K, et al. Mismatch between perceived and objectively measured environmental obesogenic features in European neighbourhoods. Obes Rev. 2016 Jan;17 Suppl 1:31–41.
41 Gebel K, Bauman A, Owen N. Correlates of non-concordance between perceived and objective measures of walkability. Ann Behav Med. 2009 Apr;37(2):228–38.
42 Lopez RP, Hynes HP. Obesity, physical activity, and the urban environment: public health research needs. Environ Health. 2006 Sep;5(1):25.
43 van Lenthe FJ, Mackenbach JP. Neighbourhood deprivation and overweight: the GLOBE study. Int J Obes Relat Metab Disord. 2002 Feb;26(2):234–40.
44 Catlin TK, Simoes EJ, Brownson RC. Environmental and policy factors associated with overweight among adults in Missouri. Am J Health Promot. 2003 Mar-Apr;17(4):249–58.